Final Report for the ONR Project:

High Resolution Time Series Observations of Bio-optical and PhysicalVariability in the Arabian Sea

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Abstract

A mooring instrumented with optical and physical sensors within the upper 300 m was deployed for two consecutive 6-month periods (October 15, 1994 through October 20, 1995) in the central Arabian Sea (15° 30'N, 61° 30'E). Both the Northeast (NE) and southwest (SW) Monsoons were observed. During the NE Monsoon, wind speeds averaged 6 m s^{-1} and reached up to 15 m s^{-1} during the SW Monsoon. Intermonsoon periods (Spring, SI, and Fall, FI) were characterized by weak and variable winds. Shortwave radiation and photosynthetically available radiation (PAR) displayed biannual cycles, peaking during the intermonsoon periods. The maximum winter mixed layer depth ($MLD_{1.0°C}$~110 m) was deeper than the summer mixed layer ($MLD_{1.0°C}$~80 m), primarily because of surface cooling and convection. A biannual cycle in chlorophyll was evident with greater values occurring during each monsoon and into the intermonsoon periods. High chlorophyll values associated with cool mesoscale features were also apparent during each monsoon. These mesoscale features and others have been documented using remotely sensed sea-surface height anomaly maps. Our results indicate that biological variability is important for the seasonal variability of the upper ocean heat budget of the central Arabian Sea.

Project Goals

An interdisciplinary mooring field study was conducted in the Arabian Sea (October 1994 - November 1995) as part of the ONR Forced Upper Ocean Dynamics (FUOD) Program activities in the region. The Arabian Sea experiment allowed us to study bio-optical and physical processes and their interactions under monsoonal and intermonsoonal conditions. This region was attractive because of its regular and intense atmospheric forcing which caused extremely strong responses in both the physics and biology of the upper layer. Thus, dynamical ranges in measured properties were great, enabling us to apply and test time-dependent interdisciplinary models relevant to bio-optical properties and carbon fluxes.

Scientific Objectives

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Our work addressed several scientific questions, allowed testing of specific hypotheses, and provided complementary data for collaborating scientists. Key questions included:

1. What are the dominant scales of coupling between atmospheric forcing and physical/bio-optical responses (e.g., mixed layer and stratification evolution, phytoplankton blooms and busts)?
2. What are the roles of episodic wind events, monsoons, and seasonal insolation with respect to biological/physical processes and their couplings?
3. To what degree can physical/bio-optical/biological dynamics be explained using local (one-dimensional) models? What are the responses of the mixed and euphotic layers to advective features such as filaments and eddies?
4. How can horizontal information (e.g., satellite surface temperature, topography, and color data, ship-based underway and tow-yo data) be synthesized with mooring data?
5. Do phytoplankton blooms significantly affect water column heating, stratification, and horizontal currents?

Approach

The ONR Forced Upper Ocean Dynamics (FUOD) Program utilized an array of 5 deep ocean moorings placed beneath the axis of the Findlater Jet to study linkages between large-scale patterns of wind speed and direction, ocean circulation, and biological production in near surface waters. The central (Woods Hole Oceanographic Institution, WHOI) mooring was located at 15 30N, 61 30E, the center of a 50km square with other moorings placed at the corners. The observations of primary interest for the present work were made from instruments deployed from the central (WHOI) mooring during two separate deployments (October 15, 1994-April 20, 1994 and April 22, 1995-October 20, 1995). Multi-variable moored systems (MVMS) were deployed by our group at 35 and 80m. The MVMS utilizes a VMCM to measure currents and temperature with a pressure case mounted thermistor. A variety of other sensors are used to measure photosynthetic available radiation (PAR), natural fluorescence or upwelling radiance at 683nm, stimulated fluorescence, beam attenuation coefficient, and dissolved oxygen. Conductivity was also measured at 35m. All data were sampled at 3.75min intervals. Two other MVMSs were deployed by LDEO at depths of 10 and 65m. The sensor suite was similar to that of the UCSB MVMSs.

Work Completed

Our MVMS interdisciplinary systems with sampling intervals of a few minutes were placed on a mooring beneath the axis of the Findlater Jet in October 1994 for 6 months and again in April of 1995. Remote sensing data, ship ADCP data and ship tow-yo data have been used to assist in the interpretation of this highly variable environment. The data return from the central mooring was very good considering such a harsh environment to operate underwater electronics. Six refereed papers, two unrefereed papers, three data reports, and a M.S. thesis, resulted from the project (please see references below).

Summary of Results

The FUOD central mooring instrumented with optical and physical sensors within the upper 300 m was deployed for two consecutive 6-month periods (October 15, 1994 through October 20, 1995; sampling intervals of a few minutes) in the central Arabian Sea (15 30N, 61 30E). Both the northeast and southwest monsoons were observed. During the NE monsoon, wind speeds

averaged 6 m/s and reached up to 15 m/s during the SW monsoon. Intermonsoons were characterized by weak and variable winds. Shortwave radiation and photosynthetically available radiation (PAR) displayed biannual cycles, peaking during the intermonsoon periods. The maximum winter mixed layer depth (~110 m) was deeper than the summer mixed layer (~80 m), primarily because of surface cooling and convection. A biannual cycle in chlorophyll was evident with greater values occurring during each monsoon and into the intermonsoon periods. High chlorophyll values associated with cool mesoscale features were also apparent during each monsoon. These mesoscale features and others have been documented using remotely sensed sea-surface height anomaly maps. Time series of the 1% light level depth, $h_{1\%}$, tracked the depth-integrated chlorophyll. In general, $h_{1\%}$ was deeper than the MLD during the latter half of the spring intermonsoon (low chlorophyll periods) and shallower than $h_{1\%}$ during the latter portions of the monsoons (high chlorophyll periods). The highest mixed layer radiant heating rates occurred during the intermonsoon periods with peak values greater than 0.15 C d^{-1}. These values are consistent with those previously suggested for the central Arabian Sea. Our results indicate that biological variability is important for the seasonal variability of the upper ocean heat budget.

Impact/Applications

Improved understanding of temporal variations of the physical and optical properties of the upper ocean in the Arabian Sea has resulted from our advanced sampling systems and analyses. Predictive modeling of interdisciplinary processes is being made possible through our research efforts. Our work is also important for relating upper ocean particle fluxes with those at depth.

Transitions

Results from the present work will be valuable for developing models of physical and optical variability in complex regions where intense atmospheric forcing occurs, differing water masses merge, and mesoscale features are ubiquitous and energetic.

Publications

Arabian Sea Refereed Papers:

Dickey, T., J. Marra, R. Weller, D. Sigurdson, C. Langdon, and C. Kinkade, Time-series of bio-optical and physical properties in the Arabian Sea: October 1994 - October 1995, Deep-Sea Res. II, 45, 2001-2025, 1998.

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Also, please see web site http://www.opl.ucsb.edu